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PHOSPHORUS BIOAVAILABILITY OF THE AVON RIVER

TECHNICAL REPORT S - 12

STRATFORD-AVON RIVER
ENVIRONMENTAL MANAGEMENT PROJECT

PREFACE

This report is one of a series of technical reports resulting from work undertaken as part of the Stratford Avon River Environmental Management Project (S.A.R.E.M.P.).

This two-year Project was initiated in April 1980, at the request of the City of Stratford. The S.A.R.E.M.P. is funded entirely by the Ontario Ministry of the Environment. The purpose of the Project is to provide a comprehensive water quality management strategy for the Avon River Basin. In order to accomplish this, considerable investigation, monitoring and analysis has taken place. The outcome of these investigations and field demonstrations will be a documented strategy outlining the program and implementation mechanisms most effective in resolving the water quality problems now facing residents of the basin. The Project is assessing urban, rural and instream management mechanisms for improving water quality.

This report results directly from the aforementioned investigations. It is meant to be technical in nature and not a statement of policy or program direction. Observations and conclusions are those of the author and do not necessarily reflect the attitudes or philosophy of all agencies and individuals affiliated with the Project. In certain cases, the results presented are interim in nature and should not be taken as definitive until such time as additional support data is collected.

Reference to equipment, brand names or supplies in this publication is not to be interpreted as an endorsement of that particular product or supplier.

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ABSTRACT

A one year study of seven sites along the mainstem Avon River was conducted in order to evaluate the temporal and spatial changes in 'biologically available phosphorus'. The first two sample sites characterized the upstream agricultural portion of the basin, the next two represented the urban catchment while the remaining three were located in the downstream agricultural region of the Avon watershed. The thirteen sample dates included all seasons as well as a range of flow regimes which included storm events, peak spring melt flows and a variety of flow conditions. Instream loads of particulate bioavailable phosphorus were calculated for eleven of the sample dates while six dates included measurements of soluble phosphorus, which allowed an estimate of the total bioavailable P loading of the Avon River.

Spatially the upstream reaches were found to be delivering a relatively small proportion of the particulate loading. The urban sites exhibited the highest particulate loads, which then tended to attenuate in the downstream reaches. The soluble portion of the total P loads was noted to increase in the downstream agricultural reaches during a range of flow events indicating diffuse soluble inputs.

Temporally, fluxes of particulate bioavailable phosphorus were greatest during spring melt and at a minimum during summer low flows. Low frequency, high intensity events such as summer storms were noted to move more material than several longer term rainstorm events, although fall storms were not well represented in the data set.

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THE BIOAVAILABILITY OF PHOSPHORUS IN THE AVON RIVER

INTRODUCTION

A report to the International Joint Commission in 1980 identified a number of information needs regarding phosphorus management strategies for the Great Lakes. One of the needs was a better understanding of the bioavailability of various forms of phosphorus.

Historically, the majority of studies in the Great Lakes basin have focussed on values of total phosphorus (TP) concentration and/or loads. In the past decade several studies (DePinto et al. 1981, Williams et al. 1980, Cowen and Lee 1976, Sagher 1976) have indicated that a substantial portion of the total phosphorus component is not utilized by aquatic organisms. Therefore, when this historical TP data is used in the development of phosphorus load regulations for controlling eutrophication a number of inadequacies surface. The total phosphorus parameter may be of little relevance to the problem, but what is of concern is that portion, or those forms of P which are available for plant growth and metabolism. It is this portion which is generally referred to as the biologically available phosphorus (BAP).

The term biologically available phosphorus (BAP) is somewhat ill-defined due to the fact that it is an operational definition which therefore varies from one study to another. Variables which often alter between studies include the bioassay organism, chemical extraction techniques and time scales. Sonzogni et al (1982), have attempted to overcome this problem by defining BAP in terms of their operational methods and as well by introducing the term potentially bioavailable phosphorus. They imply that the various bioassays and chemical extractions undertaken to determine BAP are actually the upper limits, which therefore result in over estimates of P which is utilized by the plants in the aquatic environment.

Analytically, phosphorus can be defined as soluble and particulate fractions. It is readily accepted that the soluble orthophosphate is available to algae and other aquatic macrophytes (Logan, 1982). Yet the particulate fraction is composed of a variety of forms of P, not all of which are utilized for plant metabolism.

Chemical fractionation of particulate phosphorus identifies the three common forms - organic, apatite and non-apatite inorganic. To date laboratory studies on lake sediments and lake tributary suspended sediments indicate that apatite (the mineral form of calcium phosphates) is generally unavailable, organic forms are available to some extent over longer time periods (weeks to months) and that some fraction of the non-apatite inorganic form is readily available for plant use (Williams et al. 1980).

The determination of algal available P fractions can be achieved through bioassays. These techniques are costly and time consuming and have therefore led to investigations of the correlation between BAP and chemical phosphorus fractions (Canviro 1983, DePinto et al. 1981, Williams et al. 1980, Cowen and Lee 1976, Sagher et al. 1975, Golterman et al. 1969).

While available P has not been found to be in constant proportion to the total sediment P it has been directly related to the non-apatite inorganic (NAIP) fraction (Williams et al. 1980). In a widely used fractionation scheme developed by Williams (1976) NAIP is determined with two chemical extraction procedures using NaOH and CDB (citrate dithionite bicarbonate). While they both extract aluminum and iron associated inorganic phosphorus as well as loosely absorbed P, the CDB extraction is considered to be more rigorous (Canviro, 1983).

Logan et al. (1979), considered NaOH-P to be the short term bioavailable fraction while the sum of NaOH-P and CDB-P (NAIP) was considered to be potentially available over longer periods of time. The inorganic portion of the base extractable particulate phosphorus has been noted to have a relatively high biological availability in a number of bioassays (Williams et al. 1980, Cowen and Lee 1976, Sagher et al. 1975). DePinto et al. (1981) used the same chemical fractionation technique as Logan (1979) and compared these values to algal uptake. They found that both the NaOH and CDB fractions correlated significantly with short term biological uptake. It was apparent from their data that while the rate of release for these two fractions could be different, they were both contributing phosphorus which was utilized by the algae.

In the recent past several watershed studies have focussed on characterizing the sources and fluxes of BAP. Diffuse source phosphorus inputs to a stream system are a function of three major factors, basin geochemistry (Logan, 1978) land use activities (Omernik 1976) and agricultural practices (Logan, 1977). Three quarters of the diffuse source P loadings to the lower Great Lakes have been noted to be sediment related, with the majority of this material moving in high flow events (Army Corps of Engineers, 1979). The proportion of the tributary load measured at the mouth, but which originates from point sources within the watershed is a function of the type of activity discharging effluent and its location in the watershed.

Several studies on Great Lakes tributary basin sediments have attempted to determine the proportion of the sediment P load which is biologically available (DePinto et al. 1981, Victore 1981, Logan et al. 1979). Victore (1981), sampled five Lake Erie watersheds several times during high flow events and found that the TP content of the suspended sediments showed little variation among samples from a given tributary. Greater variation existed among TP samples from different tributaries. This pattern was also evident for the chemically defined P fractions.

Logan et al. (1979) analyzed 36 Lake Erie tributaries and sampled predominantly during high flows. He found that the biologically available phosphorus estimated by NaOH-P varied from 30-42% of the total sediment inorganic P, whereas the NAIP portion represented 75-89% of that fraction. DePinto et al. (1981), studied the same watersheds as Victore and found BAP (by algal uptake) to range between 6-35% of the total particulate phosphorus. This variability of BAP in the tributary sediment load is a function of a number of factors including i) sediment composition ii) origin of material and iii) biological and physical instream processes.

Studies of wastewater particulate BAP have been carried out by Canviro (1983), Young et al. (1982), and DePinto (1980). Young et al. (1982), sampling before, during and after treatment at four sewage treatment plants in the Great Lakes basin found on average that 63% of the total particulate phosphorus was available to algae. DePinto et al. (1980), observed that a range of 30-85% of the total particulate P was bioavailable. In this study it was concluded that the various methods of treatment used in the plants to reduce phosphorus had little effect on the relative proportion of BAP to TP. The recent study by Canviro (1983) which compared nine sewage treatment plants in Southern Ontario indicated that digester supernatant particulates had the highest proportion of BAP (50% of TP) while influent particulates had the lowest proportion of BAP (36% of TP). The BAP of the primary, secondary and filtered effluents generally fell between these values.

The focus of the above mentioned studies has been to emphasize the point source loadings to streams and the total watershed contribution to lakes. While the studies aided in evaluating some management problems, the watershed management of diffuse source inputs and the fate of point source inputs in downstream reaches has not been addressed. Carlson et al. 1978, suggested that streams have a natural ability to reduce the proportion of bioavailable P contributed from upstream sources. An

attenuation of available P could be a function of biotic uptake which transfers BAP to stored phosphorus and/or the settling of particulate materials in slow reaches of the channel.

STUDY OBJECTIVES

In an attempt to evaluate the downstream changes in BAP and their relationships with various activities within a watershed, a one year study was conducted in the Avon River basin of southwestern Ontario.

Sampling was undertaken in all seasons and under both high and low flow conditions. The objectives of this study were: 1) to evaluate the spatial variation of biologically available phosphorus in order to determine the relative importance of contributing sources (point and non-point) of P forms within the watershed; 2) to evaluate the spatial pattern of P forms downstream from the sources; 3) to evaluate the temporal fluxes of biologically available P from the sources; and 4) to consider the ramifications of these findings to alternative management strategies for effective BAP control.

THE AVON RIVER WATERSHED

A water quality study of the Thames River Watershed (1975) identified the Avon River sub-basin as a site for further study in order to determine optimal solutions to existing water quality impairment problems. A two-year Stratford-Avon River Environmental Management Project (SAREMP) focussed on evaluating urban, rural and instream options. A limited time frame and study scope was imposed on the project in order to collect salient information regarding effective management strategies.

The Avon River drains a 166 km^2 area, which is a sub-basin of the Thames River watershed. The topography of the basin is relatively smooth with only 5.4% of the watershed having slopes greater than 5% (Coleman, 1982). The eastern headwater section of the basin exhibits a gently

undulating topography while below Stratford the basin is flat, the river banks representing the major breaks in slope. The urban area of Stratford, located approximately in the center of the basin comprises 11% of the basin area while woodlots account for 8%. Agriculture is the predominant form of land use and is composed of mixed as well as monoculture practices (Coleman, 1982).

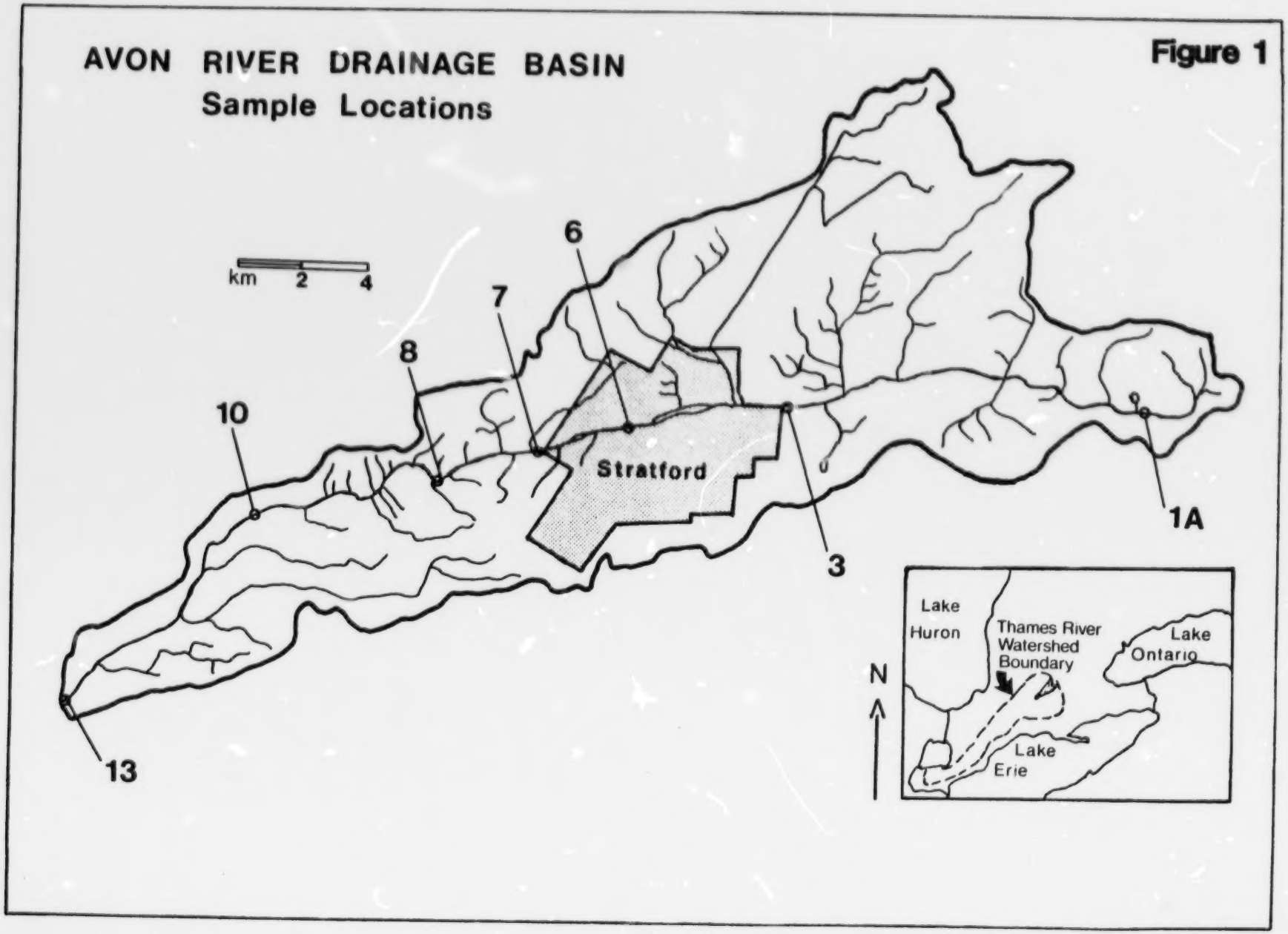
On average the annual flows of the Avon River vary between 4.0 m^3/s during spring melt and 0.45 m^3/s during summer months. Extremely low flows have been recorded with up to 50% of the total flow originating from the sewage treatment plant effluent. The mean total precipitation (30 year) is 98.15 cm/yr. Roughly three quarters of this falls as rain, the remainder as snow (Greck et al. 1982).

METHODS

Sample Sites

Seven sites on the mainstem Avon River were selected for bulk sediment collection. Figure 1 indicates the position of these sample sites within the watershed.

Two upstream sites (1A and 3) were situated in the rural agricultural portion of the basin where the steeper slopes exist, whereas sites 6 and 7 were located within the urban area of Stratford. Site 6 was just downstream of a small urban reservoir and immediately upstream of the sewage treatment plant effluent outfall while site 7 was near the city limits 1.5 km downstream of the sewage treatment plant outfall. Major stormsewer outflows occur immediately above and approximately one kilometer upstream of site 7. The three remaining sites were in the downstream reaches of the watershed where agricultural practices again predominate. Site 10 was also the location of a federal stream flow gauge which enabled loading calculations for sediment and phosphorus


AVON RIVER DRAINAGE BASIN
Sample Locations
Figure 1
km 2 4
6
7
8
10
Stratford
3
1A
13
N
Lake Huron
Thames River Watershed Boundary
Lake Ontario
Lake Erie

fractions. Although provincial flow gauges were present at each of sites 1A through 8, the data are very sparse and of limited use in this study.

Field Methods

The field collection of sediment and water samples from the seven sites in the Avon watershed took place on 13 dates over a period of one year. At each site the culvert or bridge, which served as a road crossing, was used as the access point. Two submersible pumps were positioned at one-third and two-thirds of the stream width and were lowered to approximately mid-depth of the stream cross-section in order to obtain a representative suspended sediment sample.

Water and the associated suspended material were collected in 10-50 litre carboys (during periods of high flow and/or turbidity less water volume was required to obtain sufficient sediment). The time of sampling and the temperature of the stream water was recorded along with observations on stream flow and weather conditions. Two, one-litre samples of pumped water were collected for aqueous parameter analysis by the Ontario Ministry of Environment (MOE) laboratory in London (this included total phosphorus (TP), dissolved reactive phosphorus (DRP), suspended solids (SS), total dissolved solids (TDS), nitrogen forms and chloride).

The carboys of water were transported to the mobile laboratory (located at the sewage treatment plant) and transferred into holding tanks. This water was then pumped through a Westfalia (Model KDD-605) high speed centrifuge to extract the solids. (at a rate of six litres per minute and 9,400 RPM).

The sediment collected in the centrifuge bowl was then transferred to a plastic container for freezing and subsequent freeze drying. Following freeze drying, the sediment was weighed to determine the concentration of suspended solids. The freeze dried sediment was stored for future phosphorus fractionation.

The seven sampling sites were sampled in this method over a time period of approximately eight hours. During non-events it was believed that this time period could synoptically characterize sediment movement along the length of the Avon River. During storm events, the basin response time was faster, such that synoptic data could not be collected at all seven sites. Thus sites 1A, 3, 7 and 13 were sampled. A period of four hours was required to complete this sampling. High spring flows which persisted for a number of days, enabled synoptic sampling of all sites (assuming they were accessible, i.e., free of ice and snow and/or not inaccessible due to road flooding).

Laboratory Methods

Freeze dried sediment was analyzed for the various chemical forms of phosphates. The analytical method used (Canviro, 1983) was an adaptation of the Williams and Mayer (1981) procedure. Fourteen of the 81 samples were also further analyzed with an algal bioassay as developed by DePinto (1981).

In summary, sediment phosphorus is chemically separated into four fractions - total phosphorus, organic, apatite and non-apatite inorganic (Williams and Mayer, 1981). Organic phosphorus is determined by total extractable P minus total inorganic P (sum of apatite and NAIP). The iron and aluminum associated phosphates are removed by two extractions, the first being a citrate dithionite bicarbonate exposure for 15 minutes at 85°C. This extractant is referred to as CDB-P and includes loosely adsorbed phosphates along with Fe and Al associated phosphates. The residue from this treatment is then exposed to 1N NaOH for 16 hours where the remaining Fe and Al phosphates are removed. The sum of NaOH-P and CDB-P is the NAIP fraction. The residue was exposed subsequently to 1N HCl for 16 hours to determine apatite P directly.

Total extractable phosphorus is not always the same value as total P as the resistant phosphorus forms are not extracted in the HCl, NaOH sequence. These resistant and/or inert P forms are essentially of no interest environmentally, as they do not cycle through the aquatic system. Total extractable P is determined in order to obtain a better estimate of organic P by subtraction. The total P value is derived by measuring the orthophosphorus resulting from strong acid digestion of all forms of phosphorus in the sample.

Due to time and resource restraints, algal assays were performed on only 14 of the collected sediment samples. Six samples from September 14 and March 31, as well as two site 13 samples from August 4 and March 30, underwent both chemical and biological phosphorus extractions.

A dual culture diffusion apparatus (DCDA) (DePinto et al. 1981) was used in the bioassay as it allows the algal population to remain separate from the sediment. As well this enclosed system enables better phosphorus mass balance calculations. General procedures for obtaining a 14-day phosphorus mass balance follow:

1) A 10-14 day old P-starved uniform algal assay culture of Selanastrum Capricornutum was placed in the right side of the DCDA.

2) River sediments suspended in algal growth media (minus P) were introduced into the dark chamber (this was darkened to reduce any indigenous algal growth during incubation).

3) Harvestings of the algal population occurred on the sixth and thirteenth day in order to determine their total P uptake.

4) At the end of the thirteenth day total phosphorus, as soluble and particulate fractions was determined for both chambers.

5) A materials balance on all components of the DCDA was undertaken in order to determine the quantity of bioavailable P.

RESULTS

The thirteen sample dates selected to represent Avon River water year included a variety of both flow regimes and antecedent conditions. In studies of sediment delivery and/or stream loadings of sediment, qualitative characteristics of each sample period must be assessed in conjunction with the quantitative evaluations of the event. Antecedent conditions within the watershed, such as soil moisture, affect the sediment supply and delivery and therefore must be considered when comparing the relative importance of each sampling date. Table 1 indicates the event date, the instantaneous Avon River discharge at the federal gauge, as well as a description of the samples position on a storm or annual hydrograph.

Note that the majority of the samples are collected on the falling limb of a hydrograph and therefore result in a low flow event classification due to the discharge value at the time of sampling. Samples collected on the falling limb of a storm hydrograph do not necessarily characterize the maximum instantaneous sediment load (Gregory and Walling, 1973). The practical difficulties of being present during the rising limb of sporadic storm events result in an acceptance of loading estimates which can generally be considered to be an underestimate of the maximum instantaneous load.

TABLE 1

SAMPLED FLOW CHARACTERISTICS

	Date	Site 10 Discharge	Classification*	Event Description
Spring '81	April 15/16	0.725	low	rising limb of a series of storms
	May 5	0.538	low	falling limb of same (above) storms
	June 1	0.102	low	falling limb of small event
Summer '81	July 6	0.387	low	falling limb of small event
	July 28	5.930	high	peak of storm
	Aug. 4	0.170	low	very low - no rain event
	Sept. 14	0.246	low	falling limb of major event
Fall '81	Sept. 21	0.116	low	falling limb of medium storm
	Oct. 5	0.867	low	falling limb of major event
	Dec. 7	2.230	high	falling limb of storm
Spring '82	March 23	8.840	high	initial spring melt
	March 30	12.300	high	spring melt
	March 32	69.900	high	highest annual flow

*A flow value of 1.0 m^3/s at site 10 was defined as the separation point between high and low flow events.

Flow Regime at the Sampled Water Year

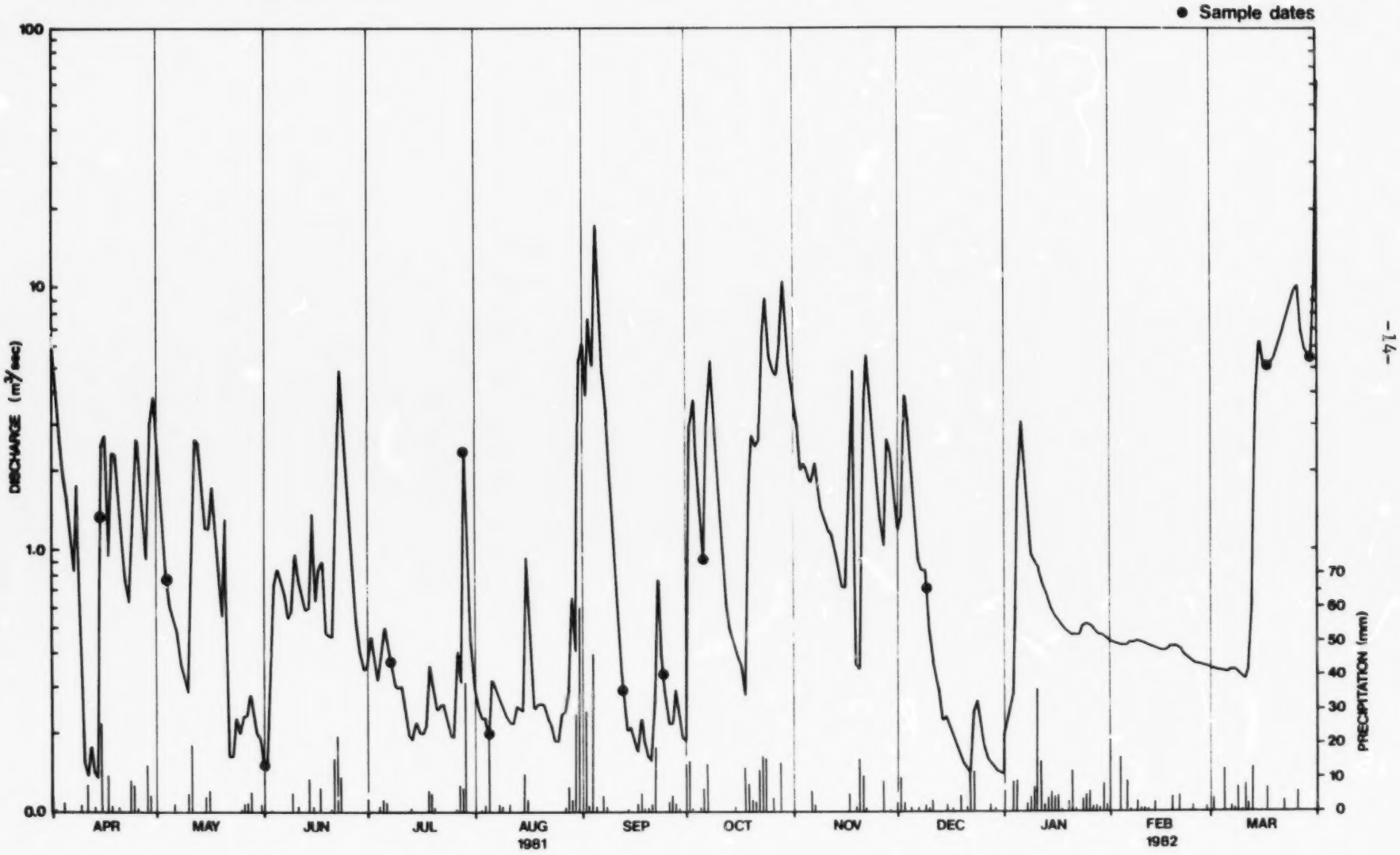
In order to assess the representativeness of the 81 - 82 water year the annual hydrograph (Site 10, daily mean discharge) presented in Figure 2 was compared to an historical hydrograph of 18 years (Figure 3). The daily mean flows for 18 years were averaged and plotted to obtain a visual estimate of the annual flow distribution. This procedure tends to dampen the 'peakiness' of annual hydrographs but does allow the general nature of the basins flow regime to be observed.

Table 2 indicates that the total volume of flow was greater during the water year sampled. During the sampling period the flow exceeded the average annual volume by 22.9%. In 1981 - 1982 the maximum daily mean discharge as well as the maximum instantaneous discharge exceeded those values observed in the 18 year historical period. These extreme values occurred during the spring melt in late March and were sampled on three separate days. The minimum daily mean discharge was slightly lower than the average annual value but it was not the most extreme value on record.

A comparison of the proportion of high and low flow volumes as well as their timing indicates that 1981 - 1982 had a relatively wet fall and a slightly drier summer. While spring flows were extreme in terms of discharge values the proportionate volume of the spring melt was 17.5% lower than the average spring high flow volume. This implies that the period of melt was less dominant with respect to annual volume but more extreme in terms of event intensity.

Sample dates are marked on the hydrograph in Figure 2. As this is a plot of daily mean discharge rather than instantaneous flows the discharge values shown do not correspond with those used in the following calculations (see Appendix 1 for instantaneous flow values).

Figure 2
Precipitation and Daily Mean Flow in the Avon River Basin for a 1981-82 Water Year.



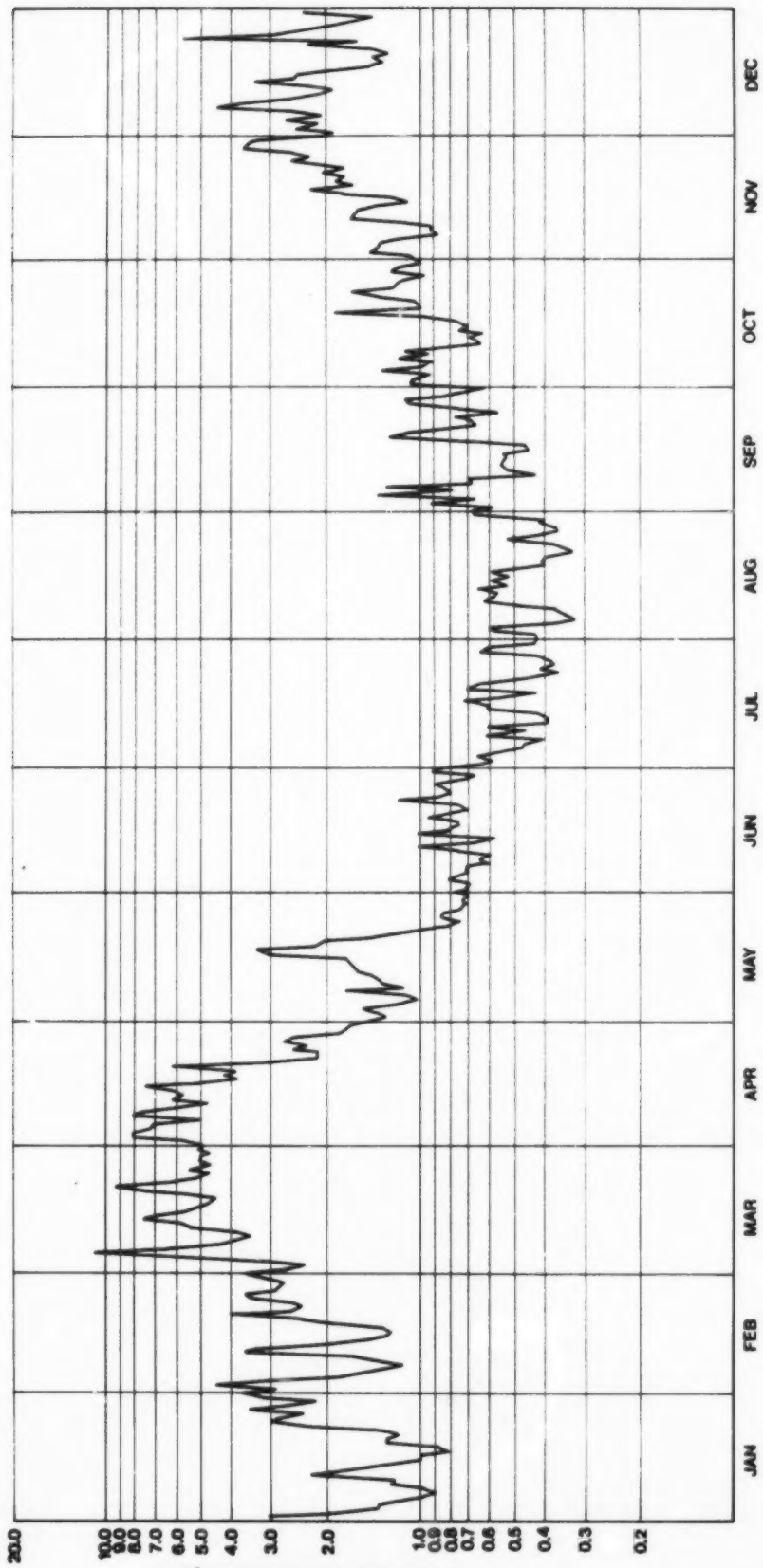


Figure 3

Avon River Averaged Annual Hydrograph
1964 to 1981, Site 10

TABLE 2

Comparison of the Sampled Water Year to the Historical Flow Record

		1981 - 1982	Historical Flow Record	
Total Flow Volume m^3/year		7.6606×10^7	6.2318×10^7	
Maximum Daily Mean Discharge (m^3/s)		66.0	43.2	(52.1)*
Minimum Daily Mean Discharge (m^3/s)		0.083	0.142	(0.040)*
Maximum Instantaneous Discharge (m^3/s)		96.5	57.3	(88.6)*
Flow Partitioning				
High Flow (greater than $1 m^3/s$)	Spring	50.5%	67.4%	
	Fall	34.5%	19.4%	
	Summer	4.1%	-	
	Winter	1.5%	-	
Low Flow		9.3%	13.2%	

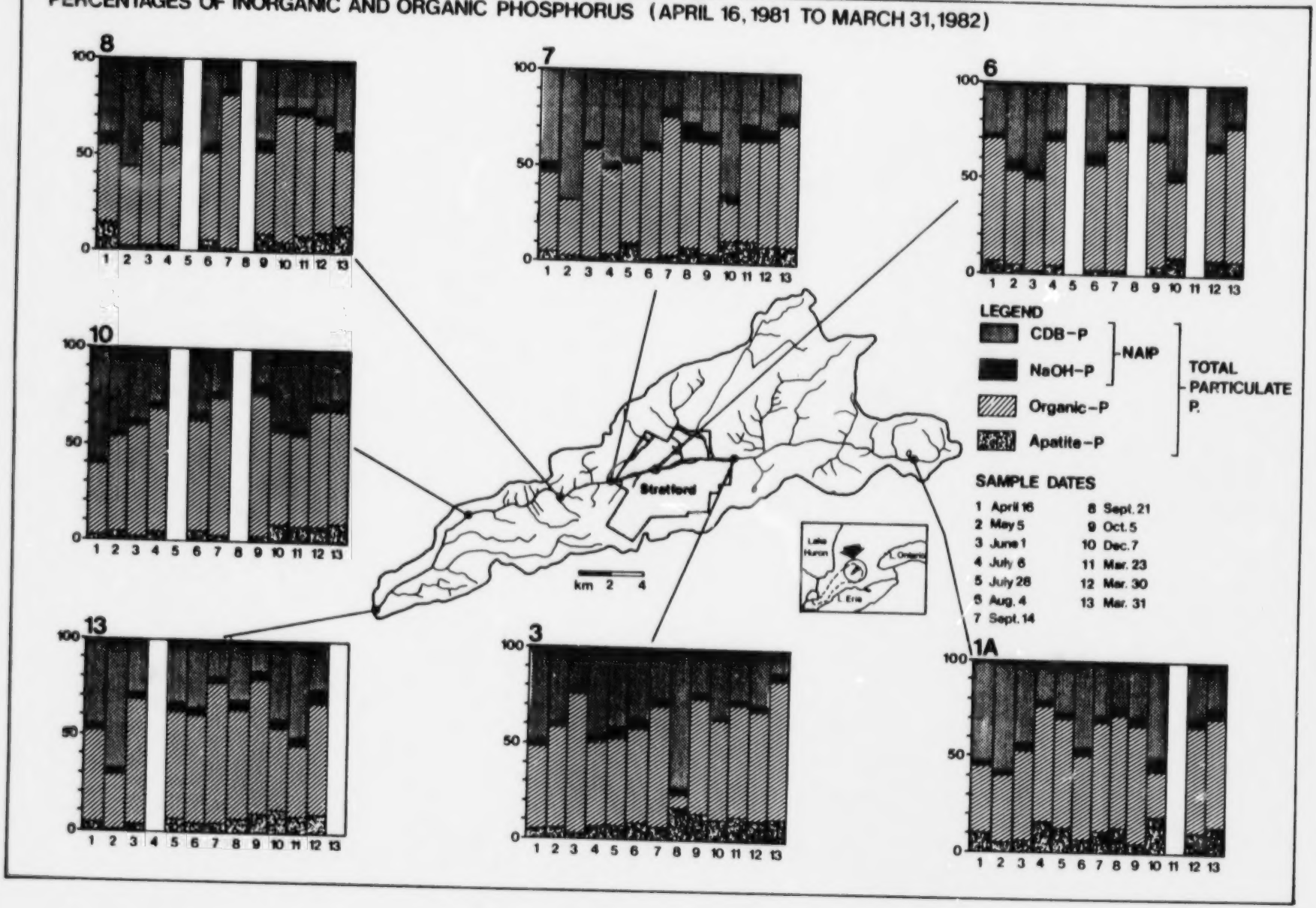
*Values in parenthesis are the most extreme values exhibited in the 18 year period.

Sediment Phosphate Composition

While the focus of this study was to investigate biologically available phosphorus, the flux of the particulate BAP was emphasized. The soluble orthophosphate is considered readily available to biota and therefore in order to estimate loadings of total bioavailable P this parameter must also be considered. Of the 13 sampling dates 6 events were sampled and analyzed for both the soluble and particulate load.

The spatial and temporal changes of the four operational forms of particulate phosphorus are presented in Figure 4. As mentioned previously the four phosphate fractions together comprise total sediment P. Figure 4 indicates the percentage composition of the fractions for all sample sites and dates. Apatite, the mineral form of phosphate comprises a relatively minor portion of the material moving in the Avon. The storm events of July 28 and September 21 as well as the high flow events of December 7 and spring melt exhibit the largest apatite values. The two upstream sites exhibit the largest proportion of apatite which most likely reflects the fact that these are headwater stations whose particulate materials reflect the surrounding soils and small watersheds rather than integrating materials from larger upstream areas as the downstream sites do.

Organic phosphorus comprises a dominant portion of the particulate materials on most of the thirteen sample dates, with the exception of two 1981 spring samples (April 16 and May 5). It is also unusually low at site 3 during the Sept. 21 storm. Recall that organic matter is generally considered to be unavailable on the short term, yet if stored along the creek bottom can be mineralized to become available as orthophosphorus.


PERCENTAGES OF INORGANIC AND ORGANIC PHOSPHORUS (APRIL 16, 1981 TO MARCH 31, 1982)
8
7
6
10
13
3
1A
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13
LEGEND
CDB-P
NaOH-P
NAIP
Organic-P
Apatite-P
TOTAL PARTICULATE P.
SAMPLE DATES
1 April 16
2 May 5
3 June 1
4 July 6
5 July 28
6 Aug. 4
7 Sept. 14
8 Sept. 21
9 Oct. 5
10 Dec. 7
11 Mar. 23
12 Mar. 30
13 Mar. 31
Stratford
km 2 4
Lake Huron
L. Ontario
L. Erie

The non-apatite portion of the sediments fluctuates between 22-54 percent. Using the extraction method of Williams and Mayer (1981) results in an NaOH-P that is not comparable to other studies which evaluated base extractable P for bioavailability. This is because the Williams and Mayer non-apatite inorganic (NAIP) fraction is determined by an an initial CDB extraction which is then followed by the NaOH extraction. In this study the secondary NaOH-P extraction consistently removes only a small portion (2-5%) of the total P while the CDB-P extraction comprises the dominant portion of the NAIP component.

By viewing data from thirteen dates sampled over a period of twelve months it appears that the organic-P particulates and the CDB-P particulates comprise the dominant portions of the particulate material and as well exhibit the greatest spatial and temporal variability.

Bioavailability as Represented by Extractions

To proceed with an evaluation of sediment bioavailability the selection of a chemical P fraction which best represented the algal assay BAP results was required. Fourteen sediment samples, of the 81 collected underwent algal uptake bioassays as well as chemical P fractionation.

Of the four sediment P fractions CDB-P and NAIP exhibit the best linear relationship with algae available phosphorus. The correlation co-efficient from NAIP versus algae BAP is .68 while CDB-P versus algae BAP is .74. The r^2 values for both of these relationships are significant at the 99% confidence limit.

From this sample set it appears that the CDB-P fraction explains a greater proportion of the variance in the short term algal available P.

With this selection of CDB-P as the best indicator of sediment BAP, the following results and discussions focus on the inputs, loadings and transfer of the CDB-P sediment fraction in the Avon River. References to particulate BAP (BAP-P) from this point refer to the chemically measured CDB-P portion of the collected suspended particulates.

Variability in the Bioavailable Portion of the Suspended Solids

Downstream and temporal changes in the percentage of particulate material which is considered available (CDB-P/TP x 100) are presented as Table 3. The mean values for each date and station, along with the standard deviations (S.D.) are presented for comparative purposes. While this view of the data does not indicate the amounts of BAP moving in the stream, it does allow an understanding of the origin and quality of the inputs as well as the changing sediment composition associated with different scales of events.

Generally the highest values are noted in the early 1981 spring samples of April and May (an anomalously high value occurred at site 3 following the Sept. 21 storm). The four samples collected in June, July and August have quite consistent mean values even though they represent a wide range of flows. The Sept., Oct. and Dec. samples were all collected on the falling limb of events of different magnitude but do not indicate any relationship to flow. The daily means of the spring melt samples show a slight decrease over the three sampling days. An evaluation of the BAP-P values by site indicates that both the means and standard deviations tend to be more consistent over time. Site 7, just downstream of the sewage treatment plant and storm sewers exhibits the largest mean proportion of BAP-P in the particulate load, but also one of the higher standard deviations. The lowest mean value occurs at site 6, an urban sample site at the outlet of Lake Victoria. Recall that this table represents the proportion of available particulate P and note the absolute amount.

TABLE 3. PARTICULATE CDB/TP PERCENTAGE TABLE, ALL SITES AND ALL DATES

Q10 / DATE / SITE	0.725 Apr. 16	0.538 May 5	0.102 June 1	0.387 July 6	5.930 July 28	0.170 Aug. 4	0.246 Sept. 14	0.116 Sept. 21	0.867 Oct. 5	2.230 Dec. 7	0.840 Mar. 23	12.300 Mar. 30	69.900 Mar. 31	Mean (S.D.)
1A	54	58	45	22	28	46	29	25	30	50	N.F.	30	25	36.8 (12.8)
3	51	42	22	46	42	38	28	73	24	37	28	30	13	36.5 (15.3)
6	28	42	47	28	N.S.	37	26	N.S.	27	47	N.S.	31	20	33.3 (8.4)
7	49	67	39	50	46	38	22	28	32	66	28	31	22	39.8 (15.0)
8	40	55	32	44	N.S.	37	17	N.S.	42	25	26	30	38	35.1 (10.5)
10	58	45	39	28	N.S.	33	23	N.S.	18	38	43	28	26	34.5 (11.5)
13	45	67	28	N.S.	33	36	20	31	16	41	50	25	N.S.	35.6 (14.6)
Mean (S.D).	46.4 (10.0)	53.7 (11.0)	36.0 (9.1)	36.3 (11.7)	37.3 (8.2)	37.9 (4.0)	23.6 (4.4)	39.3 (22.6)	27.3 (8.9)	43.4 (12.8)	35.0 (10.8)	29.3 (2.1)	24.0 (8.3)	

N.S. - site not sampled

N.F. - no flow

Q10 - site 10 discharge (m^3/s)

S.D. - standard deviation

The second approach to viewing the bioavailable material moving in the Avon River involves the calculations of BAP loadings. In the following text the term loading refers to that material which is transported through a cross section of the river at a sampling site. This load is suspended at this point in space and is presumably being transported downstream. Due to the various sinks and sources of particulate matter between the sample sites it cannot be determined if the source of the material is: i) from upstream river loadings carried during the event ii) from the river channel between sampling sites and/or iii) contributed by the subwatershed of the sampled station. As we cannot differentiate upstream processes from watershed contributions the evaluation of particulate load source is speculative, but we can identify changes in loadings between reaches of the river.

Calculations of BAP loadings involve the use of prorated discharges from a federal gauge at site 10. A 1:1 discharge to area ratio was utilized to calculate discharge at each sample station. But for the upstream sites this ratio was applied following subtraction of STP discharge (as during low flows this may represent a dominant portion of the flow).

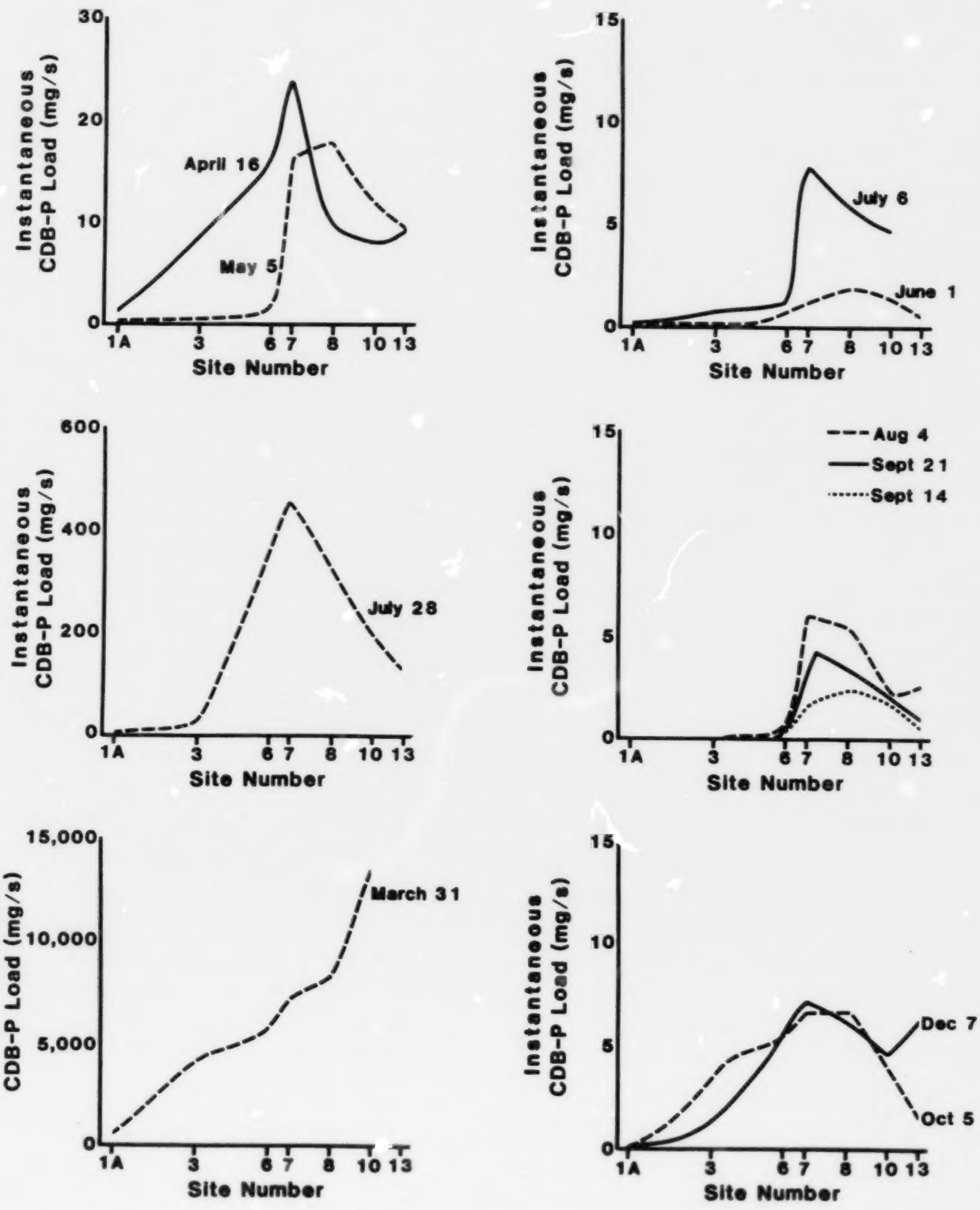
The graphs in Figure 5 indicate the downstream patterns in BAP-P loadings for the 11 sample dates available (March 23 and 30 exhibited ice flow conditions which inhibits depth gauging therefore no loadings are presented for these dates). Presentation of the data in this form reveals the relative amounts of particulate BAP associated with different scales of events and different times of the year.

The largest movements of CDB-P occur during spring melt when the sediment supply is abundant and flows are at the annual high values. March 31 is the only date which exhibits an increase in BAP loadings at all stations downstream, again a function of extreme flows and increased erosive power due to snowmelt. The loading graphs in Figure 5 exhibit a tendency for peak values to occur at site 7 and then to decrease in a downstream direction. As flow increases downstream, this occurrence would likely be

Downstream Loading Plots for Particulate Bioavailable Phosphorus

Figure 5

(note scale changes)



a function of decreasing sediment loads downstream, which may at times be coupled with reduced bioavailable portions in the suspended sediments.

The relative importance of the BAP loadings transmitted during a summer storm are apparent from the July 28 data. Note the change in scale on the y-axis, as a peak loading of 456 mg/s at site 7 exceeds all other sample date values excepting those of spring melt.

Unit Distance Loadings of BAP

In order to view the importance of each stream reach and its relative contribution of BAP, unit distant loads to the stream were calculated. Unit area loadings were also a possible choice for comparison, but as a number of events were not precipitation related it was felt that the lengths of the channel reaches provided a more appropriate comparison.

The difference between calculated daily loads from one site to the next was divided by the length of channels (i.e. tributaries and major drains) associated with that site to obtain the unit distant loading of BAP. Table 4 indicates the temporal and spatial distribution of the gains and losses of particulate BAP in the Avon system.

In assessing this data through the use of means it is not very elucidating to include the March 31 spring melt samples, as they tend to be orders of magnitude greater than the values for the other sample periods. Therefore both means are presented in table 4. It is apparent from the table that the upstream reaches exhibit net transport while the downstream reaches indicate sediment losses along their length. While the annual means (excluding March 31) indicate net losses, sites 8 to 13 do not exhibit consistent reductions of sediment load but rather vary from event to event.

TABLE 4. DAILY UNIT DISTANT LOADINGS FOR STREAM REACHES (g/km/day)

SITE	DRAINAGE AREA (Km^2)	STREAM + DRAIN DISTANCE (Km)	Apr. 16	May 5	June 1	July 6	July 28	Aug. 4	Sept. 14	Sept. 21	Oct. 5	Dec. 7	Mar. 31	MEAN	MEAN EXCLUDING MARCH 31 SAMPLE
1A	5.77	3.14	7.0	4.0	0.2	9.0	51.0	0.4	0.4	1.4	3.8	3.5	11,747	1,075.2	8.1
3	50.71	59.53	3.0	0.8	0.005	1.0	12.0	0.1	0 02	0.2	1.9	1.7	4,805	438.7	2.1
6	35.98	47.10	1.2	2.0	0.2	0.70	NA	0.4	0.1	NA	7.1	0.7	4,077	455.6	2.9
7	18.99	21.73	4.9	62.0	5.6	30.0	678.0	22.0	5.6	37.0	5.1	4.1	6,367	660.5	89.8
8	11.86	24.12	-4.8	2.0	2.0	-6.0	NA	-0.1	1.7	NA	-1.9	-1.2	3,622	396.7	-6.4
10	12.59	23.49	11.0	-23.0	-2.0	-7.0	NA	-13.0	-1.7	NA	-5.8	-2.5	7,696	850.2	-5.5
13	25.22	47.09	-4.0	-4.0	-2.0	NA	-218.0	0.7	-1.9	-13.0	-5.4	1.2	NA	27.4	27.4

NA - data not available

Total Bioavailable Loadings of BAP

For the six sample dates for which soluble phosphorus was measured, total BAP loadings at sites along the Avon have been calculated. Figure 6 portrays the breakdown of this total BAP flux into the soluble and particulate portions. Note the high flow event of Dec. 7 which is on the falling limb of a series of storms. The particulate BAP comprises a very minor portion of the total load. During clear weather when the total BAP loads are high (May 5, Aug. 4) the soluble BAP is not noted to increase until site 7. The summer storm (July 28) and the spring melt samples indicate that a notable portion of the total BAP is soluble at all stations.

DISCUSSION

The biologically available phosphorus in a stream channel may:

1) be derived from the surrounding watershed and transported to the channel during overland flow events

2) enter the stream due to anthropogenic influences such as agricultural practices or sewage treatment plant effluents

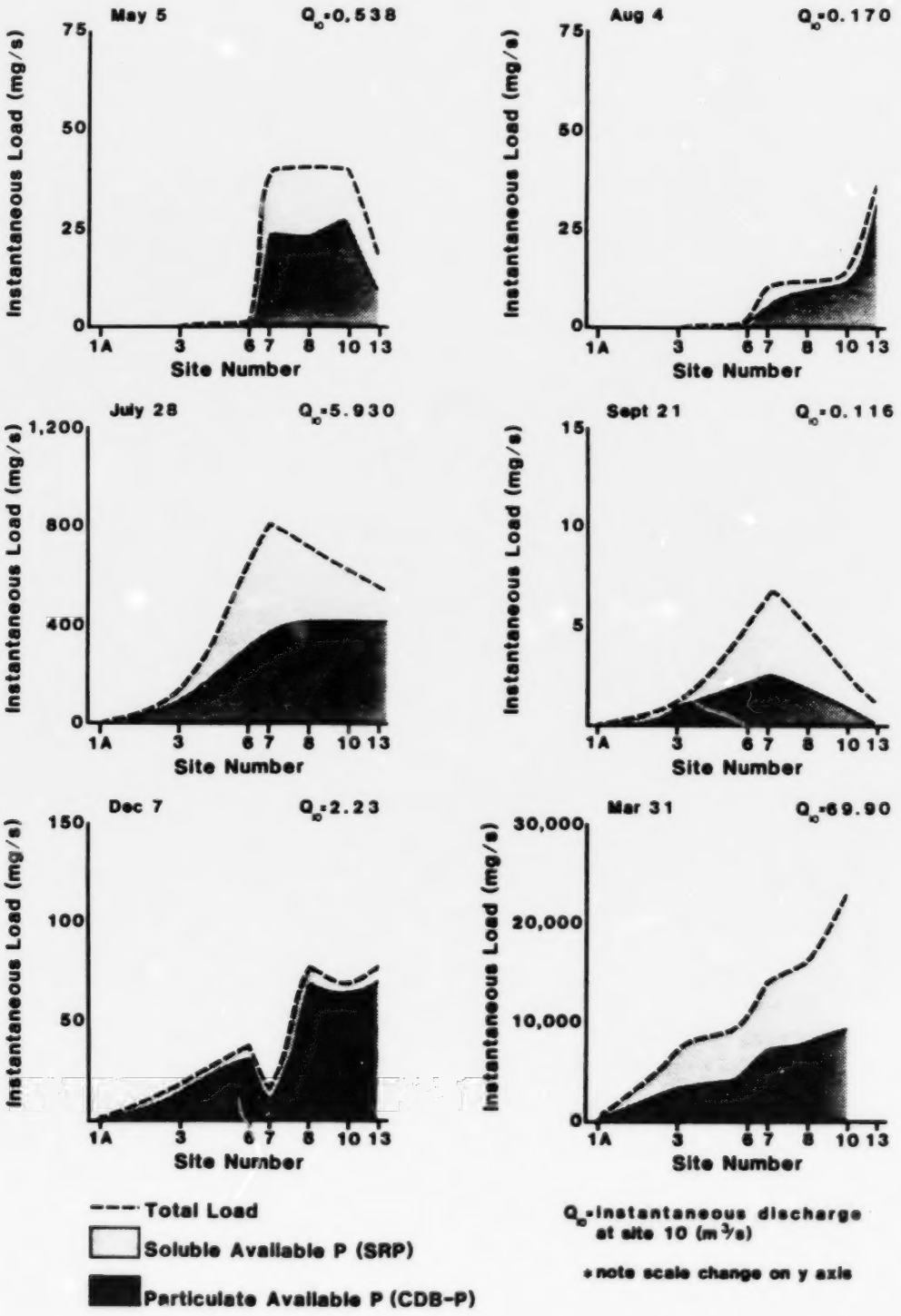
3) be a breakdown product of the biological material that has been transported or has grown in the stream

4) be stored as inorganic material in the bottom sediments.

The sources of BAP-P are varied and difficult to differentiate and there is also the removal of material from the stream along biological vectors to consider. These include root uptake by plants along the streambank, aquatic insect emergence and vertebrate migration (Meyers and Likens, 1979). These vectors not considered in this study as long-term mass balances were not of interest here.

Total Bioavailable Phosphorus Loads (CDB-P + SRP)

Figure 6



This study focuses on the changes in instream loadings, which refers to that material moving in the water column past a point of reference at the time of sampling. Therefore we can identify only problem reaches as the material changes could be a function of stored channel materials, activity of instream biota and/or watershed contributions.

Before discussing the results previously presented a review of the major assumptions implicit in this study is useful. It has been assumed that:

1) the combination of 13 events sufficiently represents the years; hydrologic activities

2) the CDB - phosporus fraction is an appropriate surrogate for 'bioavailable phosphorus'

3) the prorated flows accurately represent the actual discharges.

Rating Relationships

The material moving in the water column would be expected to have some relationship to the discharge (Q). Discharge increases with increased precipitation and generally suspended solids concentrations increase at the same time. Again these suspended materials can be derived from a number of sources but at some point the relationship between discharge and suspended solids concentration changes due to a depletion of sediment supply. Sediment rating curves often have different equations for the rising limb and the falling limb of storm hydrographs due to this sediment supply limitation.

Rating relationships for soluble phosphorus versus discharge exhibit different forms in various climatic and geomorphic regions. Again this is a function of the supply of the dissolved substance. Generally the relationship between dissolved solids and discharge is inverse, due to the effect of dilution of baseflow. Inputs of precipitation or snow melt are generally more dilute than the baseflow and therefore decreased concentrations are noted with increased discharge (Gregory and Walling,

1973). Variations in this relationship will occur if sources of the solute near to the stream are flushed by precipitation or overland flow. Surficial phosphorus fertilizers, manure leachates in soil pore water and loosely absorbed sediment orthophosphates are three sources of P which may be released in periods of increased precipitation or discharge. Again the size of these P stores change with various scales of events and at different times of the year.

A scatter diagram of flow and suspended solid concentration for the Avon River sampling period is presented in Appendix 3. As well the relationship between suspended sediment concentration versus concentration of CDB-P is presented in Appendix 3. These plots indicate the wide range of flows and CDB-P associated with a clustered range of suspended sediment (SS) concentration. This limited range of is likely a function of sampling during the falling limb of the hydrograph when the sediment peak has passed. Therefore loadings noted here can be considered conservative estimates.

While the majority of suspended sediment concentration values (excluding spring melt) do not vary widely, the loading calculations of BAP-P are a product of the SS concentrations, the ratio of available P and the discharge, which therefore results in wide variations of CDB-P loadings. Figure 7 shows how syncronous the suspended sediment loads and CDB-P loads can be during both high and low flows as well as winter and summer.

Seasonal Variations of Particulate Bioavailable Phosphorus Inputs

To identify periods of high bioavailable inputs the data in Table 3 and Table 4 should be considered in conjunction. (A series of histograms portraying the unit distant loads of Table 4 is presented as Figure 8). From this data the seasonal differences in both the percentage of bioavailable material and the movement of that material instream can be identified.

The highest daily mean values of percent CDB (Table 3) occur on April 16, May 15 and December 7, three events which exhibited flows above 0.50 m^3/s. The two upstream agricultural reaches exhibit positive unit distant loadings (compared to other non-precipitation events at these sites), as do the two urban sites. Downstream of site 8 losses of loads occur.

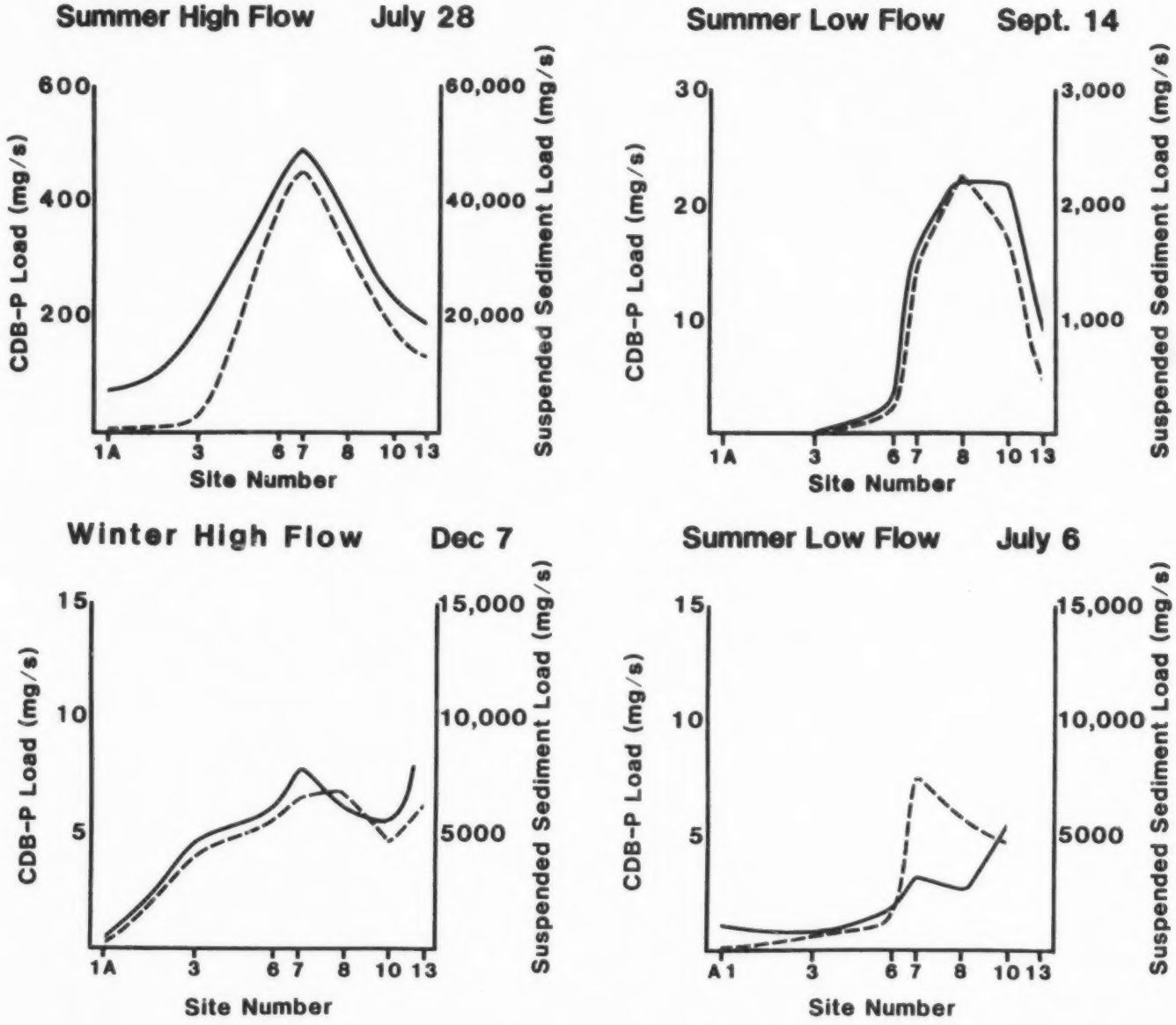
Initially we note that the available portion of the suspended sediment load is never fully depleted (the lowest observed value = 13%). A portion of the sediment was always recognized as being available, and as well the soluble P component was always detectable in samples. There was no period observed when the supply of bioavailable phosphorus was zero.

The April and May samples show high concentrations of CDB-P at all sites but more so downstream of site 7. To obtain an estimate of sewage treatment plant (STP) stream loadings the daily plant flow rate was multiplied by the effluent phosphorus concentration for that period of record. Of the 13 BAP sample dates, April 16 and May 5 exhibit the highest sewage treatment plant effluent total P loadings. (See Appendix 4) Figure 8, which portrays the unit area loadings of particulate BAP indicates the dramatic increase in BAP loadings between sites 6 and 7 on both these dates.

The early spring and winter samples may give some indication of the role of instream organisms in the instream attenuation of phosphorus. The physical barrier of the macrophyte beds is absent at these times and algal uptake of BAP would be lower due to the presumed smaller standing crop. It is interesting to note that unit losses still occur in the lower reaches of the watershed indicating that this could be a function simply of stream morphology. (i.e. sedimentation on the slip off slope of the meander bed).

Suspended Sediment and CDB-Phosphorus loads of Several Flow Regimes

Figure 7



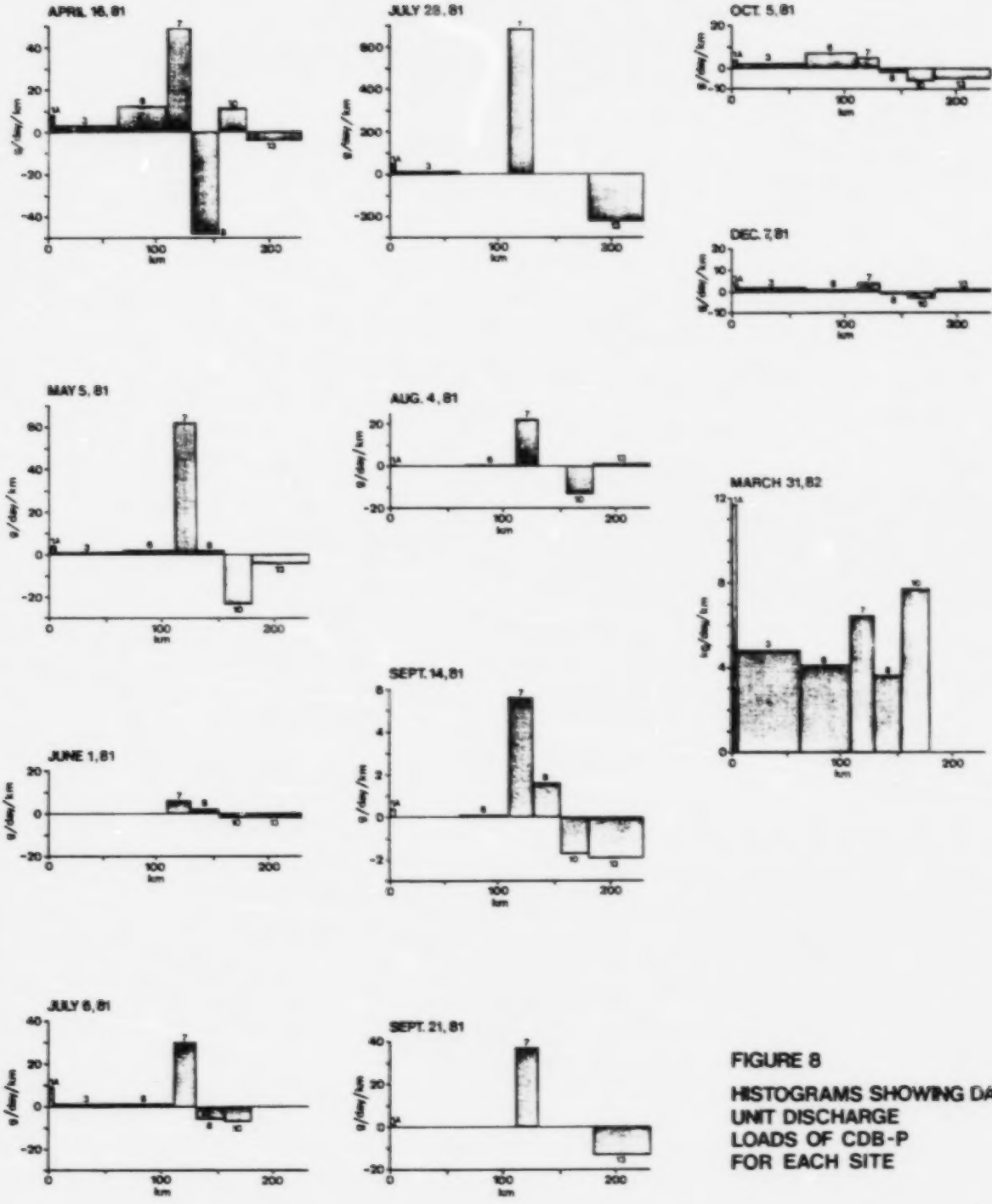


FIGURE 8

HISTOGRAMS SHOWING DAILY UNIT DISCHARGE LOADS OF CDB-P FOR EACH SITE

Intensive sampling during the 1982 spring melt (March 23, 30, 31) reveals that the mean daily values of percent bioavailable particulates tends to decrease as the event continues (Table 3). While channel bottom sediments would be scoured and removed during these annual high flows the majority of input would be derived from surficial sediments in adjacent fields due to the erosive power of meltwater on frozen ground. The flow is noted to be increasing over these three days as does the sediment load (the supply has apparently not become limiting at this stage), yet the proportion of BAP tends to decrease. This is not a marked occurrence, but possibly indicates that the sources of BAP in the sediment supply are diminishing with time. (Potentially this is a function of grain size, as the later higher flows are capable of carrying heavier sediments which are less likely to be associated with available phosphorus). We might expect to see similarly high CDB/TP values during the spring melt as in spring and winter flows (April, May, Dec.) as they all should exhibit relatively small biotic populations, but the spring melt values are masked by the extensive supply of materials which comprise a wider range of grain sizes. Loadings could not be calculated for all spring melt sample dates (due to icing effects on depth gauging) but the estimates for the sites sampled on March 31 indicate the voluminous amounts of material moving. No losses of BAP-P occur in the downstream reaches as the flows were so extreme as to preclude physical sedimentation. Presumably this material was transported to Lake St. Claire via the Thames River.

It is questionable as to whether this event period is of major significance for stream quality management (aside from erosion aspects) as the majority of material appears to be carried through the system. On the other hand it is a major concern in terms of lake management as it represents a significant portion of the annual lake loading.

The range in the magnitude of loadings sampled in June, July and Aug. 1981 have been shown in Figure 5, note especially the July 28 storm event and the August 4 low flow situation. The relative importance of the summer storm events ability to transport BAP is apparent. In the summer period when aquatic produccion is high it is perhaps useful to look more closely at the percentage of CDB-P in the suspended material. Although in periods of low flow material may not be moved, the settled sediments as well as those in the water column are available for utilization by plants. The four summer sampling dates (June 1, July 6, July 18, August 14) show a consistency in daily mean CDB-P values. The range between 36-38% includes sampling of an extreme storm event, clear weather and post storm conditions. A change in flow regime does not appear to affect the proportion of BAP in the particulate matter. Therefore it would seem that the supply remains as a consistent ratio during this period of intense aquatic growth.

The remaining sample dates include September 14, 21 and October 5. While all of these samples were collected on the falling limb of storm events there is no indication of any relationship of BAP-P/TP to flow. This could be due to the wide range of antecedent storm conditions inherent in such a wet fall which as mentioned previously would affect the supply of particulate material to the stream channel.

Unit loadings for these dates indicate positive inputs up to site 7 although the upstream contributions are quite small, and again losses are exhibited in the reaches downstream of the urban area. The trend in the upstream (1 - 6) unit distant loads is to increase from Sept. 14 until Oct. 5. This may also be an indication of the importance of instream bioutilization. As the season progresses and less standing stock is present greater portion of the material suspended is available.

Urban Inputs

A study of the Stratford sewage treatment plant (Canviro, 1983) indicated that the plant has a relatively good removal rate for BAP during normal flows in both summer and winter. Ninety-seven percent of the BAP is removed by the time the material passes through the third process of filtration. (On occasion the capacity of the STP is exceeded and the treatment process is bypassed, directing materials to the Avon River.) This efficient removal should however be viewed in context with the upstream loadings, in order that the relative impact of STP loadings can be determined.

An estimate of the relative importance of the sources of BAP (both soluble and particulate), which included storm sewers, sewage treatment plant effluent and river station loadings, was calculated for the fall storm of Sept. 21. Estimates indicate that on this date an urban storm sewer (Bedford) contributed total BAP loadings of approximately 5.68 mg/s. The sewage treatment plant input 13.06 mg/s, yet the sampling at site 7 indicates a loading of only 10.75 mg/s. Upstream of the city limits at site 3 the total BAP load was 1.79 mg/s indicating that urban inputs played a major role in the loadings of this date.

This comparison of the September 21 BAP contributions from significant sources as the only event for which storm sewer discharge, STP effluent and river discharge were simultaneously sampled. The relative importance of these sources on other dates has been estimated from less direct data.

Histograms of total (SRP and BAP-P) loadings have been prepared for the six sample dates when both forms were sampled. (Figure 9). Sites 3 to 8 (where possible) are presented in this manner to allow an estimate of the upstream agricultural contributions within the stream before it enters an urban area (below site 3), the influence of urban inputs at site 6 and the cumulative effects of the STP, urban and agricultural inputs by site 7. Note that the STP loadings are presented here as direct inputs rather

than as river loadings at the plant outfall and therefore are additional to the P loadings moving downstream from site 6.

In viewing Figure 9 recall that these are absolute loads and not unit distant inputs. As well the inputs of the sewage treatment plant are not instantaneous values as they were calculated from daily mean values of flow and phosphorus concentration (see Appendix 4).

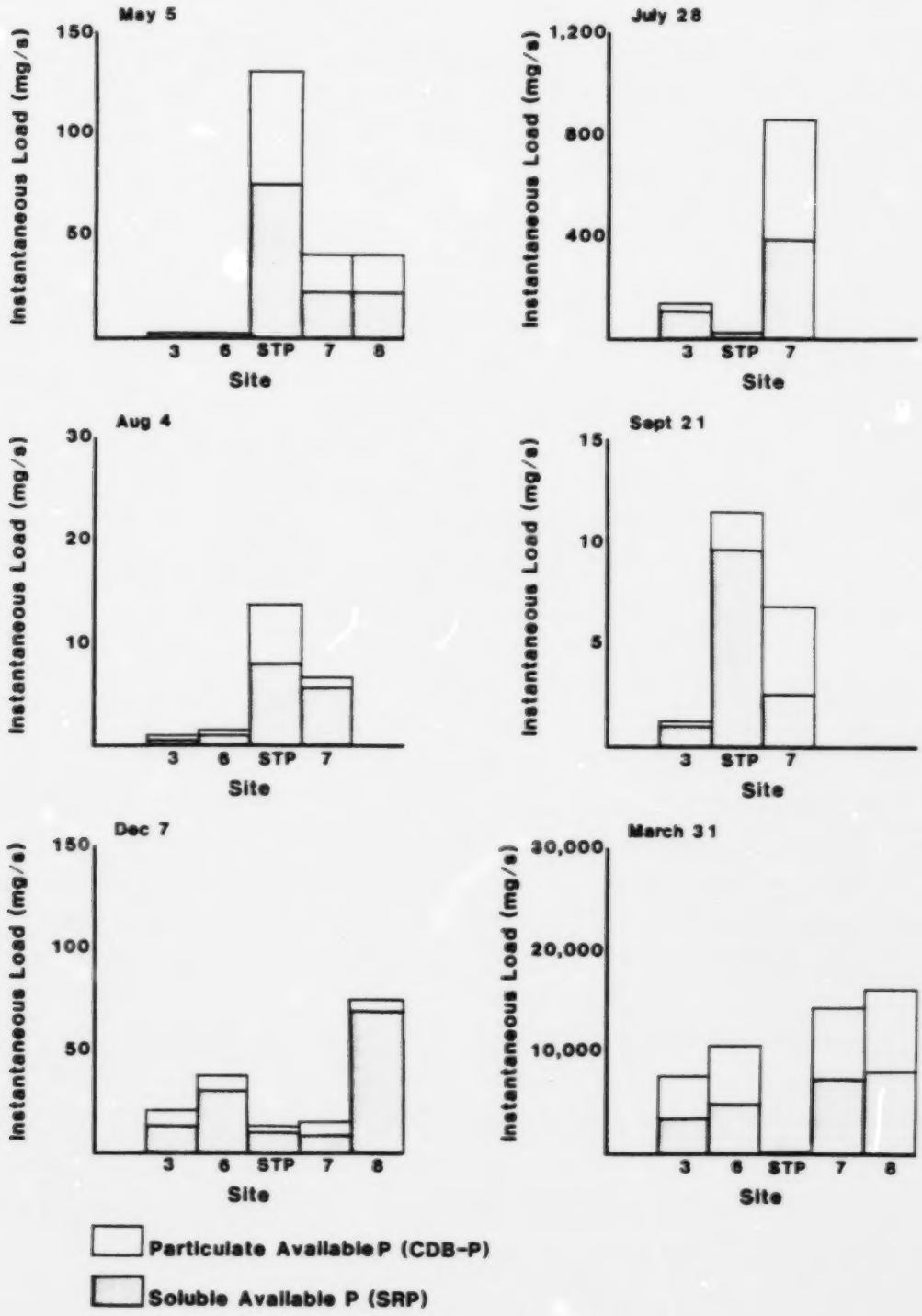
On days when the STP inflow exceeds that of the upstream inputs (May 5, Aug. 4, Sept. 21) the total load of phosphorus tends to be attenuated downstream. The site 7 values still tend to be much higher than the loadings at site 3 which is at the leading edge of the urban portion of the basin. (The increase noted in the urban area was also apparent in the unit load data shown in Figure 8). The storm of July 28 also shows this trend of increasing inputs from the urban sub-basin. While the July 28 STP values are very low relative to upstream inputs the loading at site 7 is seven times greater than that at site 3. Clearly gains of both particulate and soluble P are occurring as the stream courses through the city of Stratford.

Downstream Reach Behavior

The data for December 7 indicate that the load at site 6 is attenuated downstream to site 7, which has similar loading values as that of the STP. Yet at site 8 the soluble fraction increases dramatically. It has been noted earlier (Figure 6) that particulate material often attenuates downstream of site 7, but soluble phosphorus additions between site 7 and 8, and 8 and 10 tend to increase (on five of the six days sampled). This cannot be directly contributed to the STP inputs as the high soluble loads are not noticeable at site 7 (this conclusion rests upon the assumption of good instream mixing and therefore representative sampling of site 7). The standard downstream dilution of the soluble P load during precipitation events is not noted in this data set, which

Downstream Changes in the Composition of the Bioavailable Phosphorus Load

Figure 9



indicates that soluble P inputs are occurring in these reaches. Two probable sources are 1) the desorption or release of sediment-associated P from those materials moving in the channel and 2) diffuse agricultural inputs such as manure and fertilizer leachates and tile drain effluent.

The downstream reaches tend to be net losers in the transport of particulate P. This is important with respect to stream management as this bioavailable material is being utilized or stored in the lower reaches of the river (until a major erosive flow occurs). Weed growth would physically reduce the transport of particulates whereas weed and algal growth would utilize the soluble material transported through the reach.

So while downstream reaches are not a dominant concern with respect to transport of particulate BAP-P for the major portion of the year they are noted to be transporting a large soluble load. This load appears to be derived in the lower part of the watershed and would be immediately available to instream biota.

Upstream Reach Behavior

The particulate and soluble material which moves in the upstream agricultural portion of the watershed could easily be utilized or impeded due to biomass in the channel during most of the summer and into the fall. Yet these reaches at no time sampled, exhibited a net loss of bioavailable material. For all flow regimes they contributed material to the downstream reaches. As this is also occurring during low flow non-precipitation events, and as well since the CDB-P/TP ratio remains constant in summer one is led to believe that a short term recycling of material is occurring in the upstream reaches. During higher flow events (July 28, Dec. 7, Mar. 31) the absolute amount of transported particulate BAP increased, presumably reflecting erosion and overland transport of bioavailable material and or resuspension of stored bottom materials.

Cumulative Loadings Relative to Flow Regime

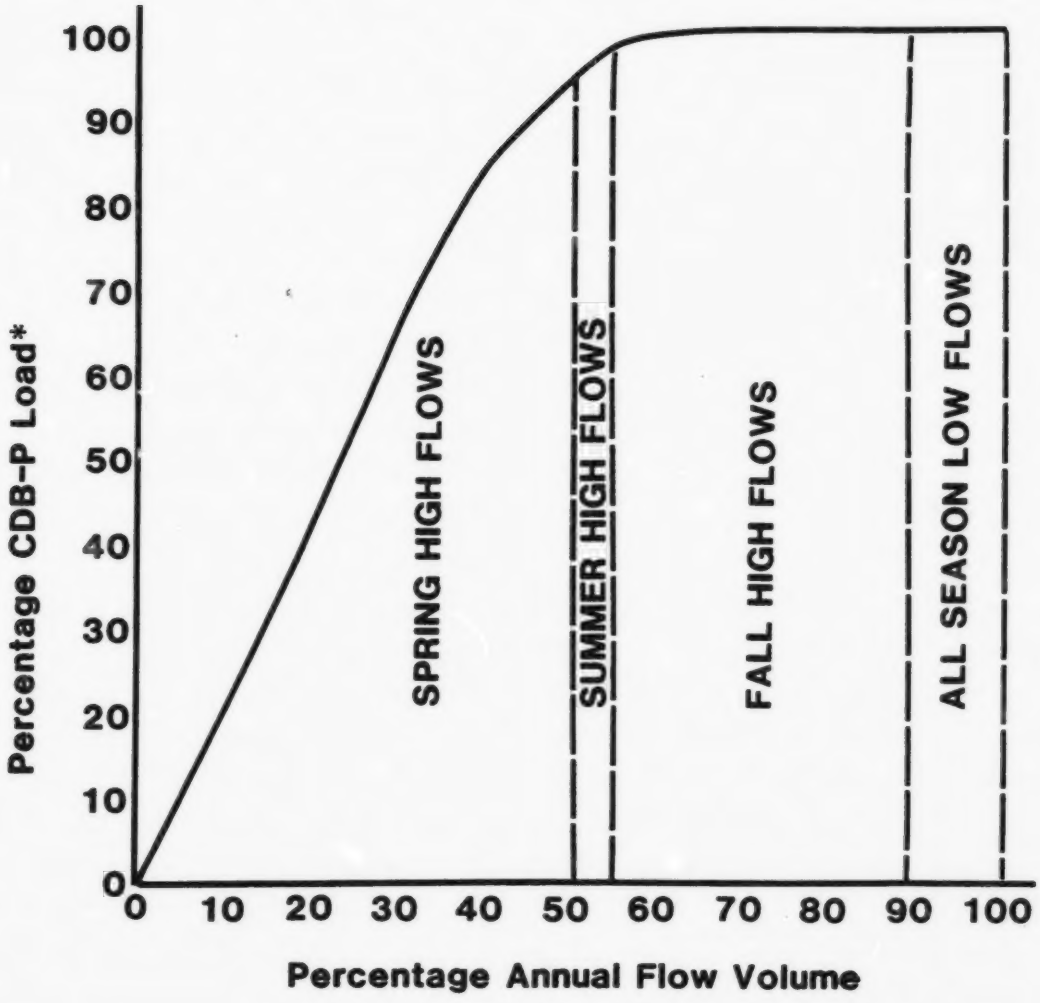
In order to assess the relative importance of the different flow regimes on the transport of particulate bioavailable phosphorus in the Avon watershed the proportions of annual flow associated with each flow regime was plotted against the flow regime proportion of the annual load of particulate BAP (see Figure 10).

An assumption of representative sampling is involved in calculating values to produce Figure 10. As load is flow related an estimate of annual load should include sample dates from each flow regime in proportion to that flow regimes contribution to the annual flow. For example if summer low flows comprise 25% of the annual flow volume, 25% of the sample dates should be during summer low flows. The data presented in Figure 10 are biased in this respect as 50% of the flow occurred in the spring melt but only one of 11 samples represents this regime in the estimation of total load. It is therefore not appropriate to consider the annual loading value as absolute but rather it facilitates relative comparisons.

In Figure 10 it appears that 96.32% of the annual particulate available load is transported in spring high flows, which comprise 50.5% of the annual volume. The next major contributor to annual loading is summer high flows which account for 3.25% of the total load while their flow volume represents only 4.1%. Fall high flows here represent 34.5% of the annual flow volume but contribute only 0.03% of the annual load. This bioavailable loading value is very likely an underestimate as: i) all 1981 fall samples were on the falling limb of the hydrographs and, ii) a greater number of peak storm event samplings are required to appropriately represent the proportion of annual flow contributed by fall storms. Low flows (defined as less than 1 m^3/s) for all seasons comprise 9.3% of the annual flow volume and deliver 0.40% of the annual load.

Figure 10

The Distribution of Particulate Phosphorus Loads with Various Flow Regimes



*the total load is cumulated from the eleven events sampled over the water year

This representation of the relative importance of the different flow regimes must be considered in the context of the ecology of rivers and lakes. While the spring melt transports the dominant portion of particulates they do not seem to remain in the watershed. The impact these particulates have on the lake environment at that time of the year will be a function of the residence time in the water column and its eventual position on the lake bottom. The summer high flows are more likely to have an impact on stream and lake production due to the abundance of primary producers. Fall high flow events (which are under represented in the sampling scheme of this project) are of less importance in the aesthetic management of riverine systems as plant biomass is declining over fall and winter. As well, any transferred BAP-P which is deposited in the channel will not remain if a major spring melt follows. But this stored material is of concern if a lake or pond exists in the system as the fall supply of BAP-P could be trapped and stored at this location until the following summer when primary production would utilize it.

Low flows do not appear to be an important contributor of particulate bioavailable loads but it is during these flow conditions that the biota have the best chance to utilize the stored particulate BAP in the channel and the soluble phosphorus in the water column resulting in high channel biomass.

Conclusions

Inputs and transfers of particulate BAP in the Avon River have been evaluated on 13 sample dates over a period of 12 months. Six of these sample dates include soluble phosphorus measurements such that total BAP loads could be viewed.

A spatial evaluation of the sources of particulate BAP indicated that the upstream reaches are delivering relatively small amounts (excluding major erosional events when all site contributions are elevated) whereas the particulate urban contribution, which includes storm sewer outflows, sewage treatment plant outflow and diffuse loadings is highest. The reaches downstream of site 7 tend to attenuate the particulate loads but increase soluble loads. This may be the area on which to focus attention as the major source of the increased soluble P appears to be diffuse agricultural inputs. These phosphorus sources are probably more amenable to load reduction than the sewage treatment plant which is presently reducing its loads to below the required limit.

Temporally the fluxes of biologically available P are greatest during spring melt and minimal during summer low flow. In this data set, intense summer storms moved more material than several longer term rainfall events. The spring melt transfers the dominant portion of the particulate BAP but this material does not remain in the Avon River system. It is transferred downstream through the Thames to Lake St. Claire. The summer high flows contributed 4.1% of the total particulate load while fall storms were under represented at 0.03%. Low flows were not a concern in terms of transportation of the particulate bioavailable loads.

Soluble phosphorus loads appeared to be proportional to particulate loadings in the high flow events indicating that the storm flow to the stream was high in soluble P. During low flows soluble P comprised the dominant portion of the load but the low flow total load represents a small proportion of the annual soluble load.

In order to manage a system of this type priority areas and/or time periods must be designated. Managers must consider two or possible three levels of resolution. In managing the Avon River this study suggests that the urban inputs are a major concern, as well as downstream diffuse loadings of soluble P.

At the scale of the Thames River management, storm events (both summer and fall) will be of concern along with the factors mentioned above.

Great Lakes management should focus on spring melt loadings and those nonpoint agricultural sources which contribute both soluble and particulate matter. The STP is far enough upstream that its effect on the Great Lakes will be dampened. Therefore federal money for the Avon River Basin would be best directed at nonpoint source control (particulate and soluble) while provincial interests should focus on reductions of urban inputs and soluble agricultural runoff.

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APPENDIX 1

AVON RIVER FLOW DATA

CALCULATED INSTANTANEOUS FLOWS* (m^3/s)

Date/Site	1A	3	6	7	8	10	13
April 15/16	0.097	0.806	0.603	0.909	1.097	0.725	1.285
May 5	0.008	0.076	0.133	0.419	0.476	0.538	0.615
June 1	0.0004	0.004	0.007	0.071	0.088	0.102	0.109
July 6	0.010	0.087	0.134	0.318	0.323	0.387	0.450
July 28	0.142	1.990	N.S.	5.338	N.S.	5.930	6.581
Aug.4	0.003	0.022	0.022	0.154	0.155	0.170	0.214
Sept.14	0.0002	0.004	0.017	0.184	0.222	0.246	0.277
Sept.21	0.003	0.032	N.S.	0.098	N.S.	N.S.	0.133
Oct.5	0.024	0.243	0.421	0.760	0.778	0.867	1.075
Dec.7	0.086	0.833	1.376	1.861	2.023	2.230	2.654
Mar.31	3.014	29.742	41.001	51.867	57.050	69.900	N.S.

* - these flows have been prorated from site 10 discharge values
  - sites 1A, 3 and 6 have been adjusted to remove the sewage treatment plant flows.

N.S. - not sampled.

APPENDIX 2

PHOSPHORUS FRACTIONS OF AVON RIVER SUSPENDED SEDIMENT

Site	Date	Percent Apatite P	Percent Organic P	Percent NaOH-P	Percent CDB-P	Concentration of Sediment Total P(ug/g)
1A	Apr.16/81	9.6	34.7	1.5	54.2	2275
	May 5/81	5.3	35.2	1.6	57.9	2750
	June 1/81	5.5	46.7	3.1	44.7	3575
	July 6/81	15.7	59.7	2.9	21.7	1300
	July 28/81	13.4	56.6	2.0	28.0	1300
	Aug.4/81	6.6	44.4	3.1	45.9	3175
	Sept.14/81	10.6	57.3	3.4	28.7	1450
	Sept.21/81	13.3	59.0	3.1	24.6	2500
	Oct.5/81	5.4	62.1	2.7	29.8	4000
	Dec.7/81	19.0	23.9	6.9	50.2	1625
	Mar.23/82	-	-	-	-	-
	Mar.30/82	11.5	56.3	2.6	29.6	1688
	Mar.31/82	13.9	56.9	4.1	25.1	1594
3	Apr.16/81	4.6	42.8	2.0	50.6	2775
	May 5/81	5.5	51.8	0.8	41.9	3500
	June 1/81	3.5	73.1	1.8	21.6	3417
	June 6/81	7.4	43.6	2.4	46.6	2250
	July 28/81	7.2	46.1	4.6	42.1	2325
	Aug.4/81	8.7	49.0	4.3	38.0	1675
	Sept.14/81	6.7	63.2	2.5	27.6	2800
	Sept.21/81	16.8	7.2	3.4	72.6	1688
	Oct.5/81	14.0	60.3	1.7	24.0	2125
	Dec.7/81	10.7	51.5	1.2	36.6	2375
	Mar.23/82	13.2	57.9	1.3	27.8	1781
	Mar.30/82	11.0	57.5	1.8	29.7	1938
	Mar.31/82	11.6	71.8	3.2	13.4	1906

APPENDIX 2

PHOSPHORUS FRACTIONS OF AVON RIVER SUSPENDED SEDIMENT

Site	Date	Percent Apatite P	Percent Organic P	Percent NaOH-P	Percent CDB-P	Concentration of Sediment Total P(ug/g)
6	Apr.16/81	6.8	64.2	.9	28.1	3750
	May 5/81	5.2	48.9	3.8	42.1	2906
	June 1/81	1.6	48.0	3.1	47.3	2575
	July 6/81	4.8	64.8	2.8	27.6	2425
	July 28/81	-	-	-	-	-
	Aug.4/81	3.4	55.4	4.7	36.5	2175
	Sept.14/81	3.1	68.3	3.1	25.5	3175
	Sept.21/81	-	-	-	-	-
	Oct.5/81	5.1	66.1	2.1	26.7	3688
	Dec.7/81	10.1	39.8	2.8	47.3	1815
	Mar.23/82	-	-	-	-	-
	Mar.30/82	8.7	57.4	3.0	30.9	2188
	Mar.31/82	8.2	69.6	2.0	20.2	2250
7	Apr.10/81	4.9	41.4	4.6	49.1	8875
	May 5/81	3.0	29.1	1.3	66.6	5625
	June 1/81	2.4	57.0	2.0	38.6	5475
	July 6/81	4.4	44.9	2.2	48.5	4750
	July 28/81	9.6	42.0	2.6	46.0	2050
	Aug.4/81	2.2	56.7	3.4	37.7	6875
	Sept.14/81	3.9	72.7	1.9	21.5	4550
	Sept.21/81	7.6	55.7	9.1	27.6	6188
	Oct.5/81	5.7	57.9	4.8	31.6	2950
	Dec.7/81	11.8	19.8	2.7	65.7	1438
	Mar.23/82	11.6	53.2	7.1	28.1	2450
	Mar.30/82	9.3	56.2	3.9	30.6	2600
	Mar.31/82	9.0	64.1	4.8	22.1	2281

APPENDIX 2

PHOSPHORUS FRACTIONS OF AVON RIVER SUSPENDED SEDIMENT

Site	Date	Percent Apatite P	Percent Organic P	Percent NaOH-P	Percent CDB-P	Concentration of Sediment Total P(ug/g)
8	Apr.16/81	14.1	40.6	5.4	39.9	3813
	May 5/81	1.3	42.2	1.0	55.5	8680
	June 1/81	65.2	1.2	32.1	32.1	5563
	July 6/81	1.8	53.1	1.4	43.7	5156
	July 28/81	-	-	-	-	-
	Aug.4/81	5.4	45.7	2.8	46.1	2258
	Sept.14/81	1.0	80.1	1.5	17.4	5750
	Sept.21/81	-	-	-	-	-
	Oct.5/81	8.7	43.3	6.4	41.6	2250
	Dec.7/81	4.8	67.5	2.2	25.5	4063
	Mar.23/82	7.5	62.8	3.5	26.2	2575
	Mar.30/82	10.1	57.0	3.2	29.7	2300
	Mar.31/82	13.9	40.5	7.9	37.7	1219
10	Apr.10/81	3.3	37.0	2.1	57.6	5844
	May 5/81	5.2	48.9	1.3	44.6	4063
	June 1/81	1.8	58.0	1.7	38.5	4375
	July 6/81	4.7	63.7	3.4	28.2	3156
	July 28/81	-	-	-	-	-
	Aug.4/82	5.3	57.8	3.7	33.2	2475
	Sept.14/81	3.1	71.5	2.4	23.0	3425
	Sept.21/81	-	-	-	-	-
	Oct.5/81	3.1	74.2	5.2	17.5	3250
	Dec.7/81	9.3	48.9	4.1	37.7	2100
	Mar.23/82	7.7	48.2	1.5	42.6	2688
	Mar.30/82	7.6	61.5	2.9	28.0	2625
	Mar.31/82	10.3	58.8	5.0	25.9	1938

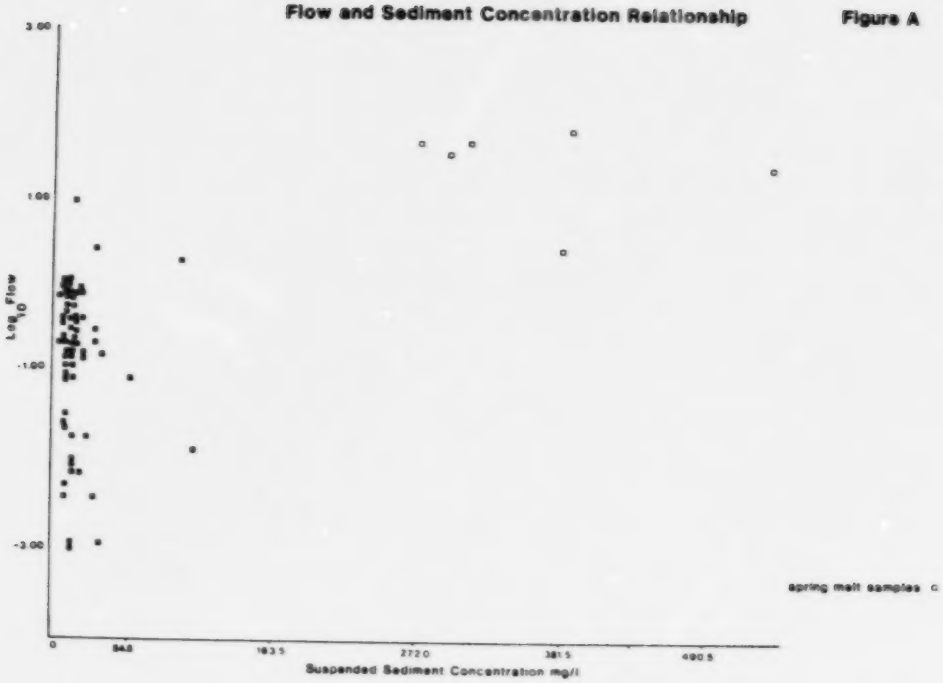
APPENDIX 2

PHOSPHORUS FRACTIONS OF AVON RIVER SUSPENDED SEDIMENT

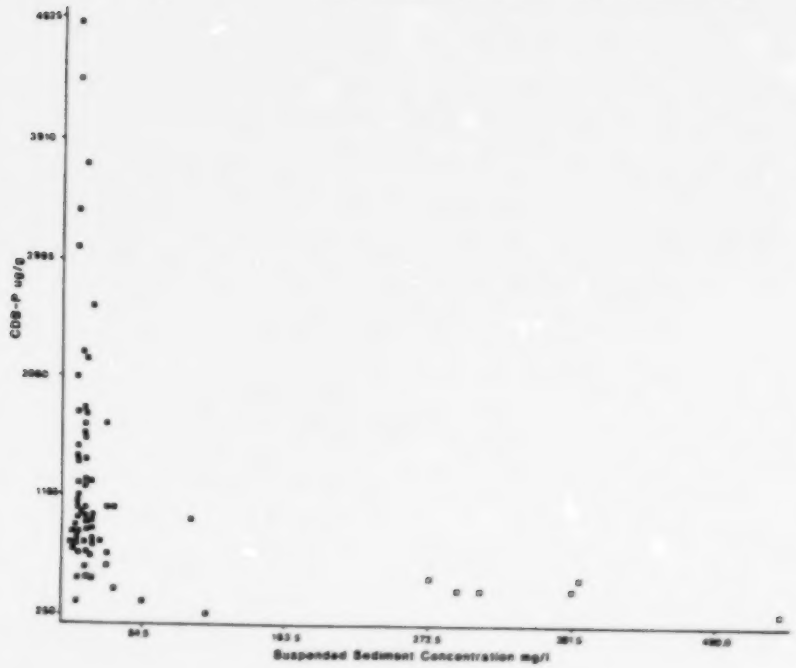
Site	Date	Percent Apatite P	Percent Organic P	Percent NaOH-P	Percent CDB-P	Concentration of Sediment Total P(ug/g)
13	Apr.16/81	4.6	47.9	2.1	45.4	3950
	May 5/81	1.3	28.8	2.6	67.3	4550
	June 1/81	3.9	65.1	2.9	28.1	3781
	July 6/81	-	-	-	-	-
	July 28/81	7.2	55.9	4.0	32.9	2125
	Aug.4/81	4.9	56.4	3.0	35.7	2675
	Sept.14/81	4.7	742.5	2.4	20.4	2550
	Sept.21/81	7.0	56.5	5.4	31.1	2150
	Oct.5/81	10.1	70.3	3.8	15.8	2050
	Dec.7/81	11.6	43.4	3.7	41.3	1938
	Mar.23/82	8.9	37.3	3.7	50.1	2425
	Mar.30/82	9.9	57.6	7.4	25.1	2187
	Mar.31/82	-	-	-	-	-

Appendix 3

Flow and Sediment Concentration Relationship **Figure A**



Suspended Sediment and CDB-P Relationship **Figure B**



APPENDIX 4

Sewage Treatment Plant Effluent Phosphorus Data

Date	Flow(m^3/s) (daily mean)	SRP conc. (mg/l)	SRP load (mg/s)	T.P. Conc. (mg/l)	T.P. Load (mg/s)	PP Load+ (mg/s)	A.P.P. Load** (mg/s)	T.A.P. Load* (mg/s)
Apr.16	0.473	0.65	307.45	1.0	473.00	165.55	49.67	357.12
May 5	0.300	0.25	75.00	0.88	2.64	187.00	56.7	131.70
June 1	0.199	0.05	9.95	0.38	75.62	65.67	19.70	29.65
July 6	0.186	0.05	9.30	0.14	26.04	16.74	5.02	14.32
July 28	0.241	0.05	12.05	0.14	33.74	21.69	6.51	18.56
Aug.4	0.156	0.05	7.80	0.18	28.08	20.28	6.08	13.88
Sept.14	0.199	0.05	9.95	0.10	19.90	9.95	2.99	12.94
Sept.21	0.192	0.05	9.60	0.11	21.12	11.52	3.46	13.06
Oct.5	0.293	0.05	14.65	0.26	76.18	61.53	18.46	33.11
Dec.7	0.197	0.05	9.85	0.09	17.73	7.88	2.36	12.21
Mar.31	0.805	0.05	40.25	0.25	201.25	161.00	48.30	88.55

+ Particulate Phosphorus Load = Total Phosphorus Load - Soluble Reactive P Load.

** Available Particulate Phosphorus Load = 0.3 (particulate phosphorus load).
(0.3 is an average value for the availability of P in sewage effluent (Canviro, 1983).)

* Total Available Phosphorus Load is determined by adding soluble P load and available particulate load.